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BIOLOGICAL ANALYSIS OF WATER POLLUTION IN NORTH AMERICA

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Biological analysis of water pollution in North America

A. F. Bartsch and William M. Ingram

With 1 table in the text

Introduction

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In North America, more than 150 biologists are currently engaged in the study or evaluation of water pollution. Since it is important that their views on the saprobic system and their use of it be considered, questionnaires were used to solicit expressions relating to use of this system or to alternate procedures.

In this paper the term, saprobic system, refers to the ecological method used to diagnose water pollution, as originated by KOLKWITZ and MARSSON (1908, 1909). Present consideration excludes the microbiota. The procedure is based on zoned distribution of indicator organisms responding to sewage pollution of slow and uniformly flowing rivers. Knowing the species occurring at given points along the course of the river, it is claimed that zones of organic pollution and recovery can be identified and delineated. KOLKWITZ and MARSSON (1908) called these zones polysaprobic, strong and weak mesosaprobic, and oligosaprobic, in order of increasing mineralization. Other workers have modified the saprobic system in various ways, or have derived alternate procedures to cover different kinds of wastes and other waters. Still others have evolved schemes to interpret the biological field findings or to portray them in more understandable form. It is not always clear whether the data processing schemes are intended to yield better understanding of fundamental principles or only to facilitate presentation. European procedures and modifications of the system have been reviewed recently by BICK (1962), and a historical survey of such developments in the United States has been made by MACKENTHUN and INGRAM (1965).

Recent publications by HYNES (1963, 1964 a, 1964 b) discuss some of the fundamental deficiencies of the saprobic system. For example, the indicator organisms available for use occur in natural habitats and did not evolve in polluted water. Many of them may be found in a range of environmental conditions. In most cases, the ecological characteristics of the organism are poorly known. Does their presence depict a response to sewage, to other organic waste, to physical qualities of the bottom, to flow velocity, dissolved oxygen, or other quality of the habitat? From studies of the bottom fauna in the sewage-polluted Illinois River over a period of years, RICHARDSON (1921, 1928) noted that the number of bottom or-

ganisms that can be safely regarded as dependable indicator organisms is surprisingly small. Others subsequently have come to a similar conclusion.

In North America, as in Europe, many workers have shifted from using the saprobic system alone to the sounder position of examining certain elements or the entire biocoenose and usually combining these observations with chemical, physical, physiological, and other observations. Some of the better-known American approaches are those used by Ellis (1937), Brinley (1942), Bartsch (1948), Bartsch and Churchill (1949), Patrick (1949, 1950), Henderson (1949), van Horn (1949, 1952), Gaufin and Tarzwell (1952, 1956), Biglane and LaFleur (1954), Beck (1954, 1955), Wurtz (1955), King and Ball (1964), Hirsch (1958), Bartsch and Ingram (1959), and Beak (1964 a, 1964 b). Others (Bartsch, 1960; Odum, 1956; Hull, 1962; and Copeland and Dorris, 1964) have explored the significance of diurnal fluctuations in dissolved oxygen. Symons, Weibel, and Robeck (1964) have developed a photosynthometer to expedite such studies.

Although circumstances are better known for the United States than for Canada or Mexico, there is an obvious current of unrest among North American biologists as to the investigative approach to use. Only a small minority now use the saprobic system as a step in the practical task of abating water pollution. A number of reasons account for this. Some of them are apparent in the system deficiencies already referred to, but other reasons, perhaps, are peculiar to the North American continent. In addition, the following questions influence the course of action when biological investigation is contemplated: What is the real problem to be studied? What kinds of information are needed to help in solving it? What is the most effective and efficient approach? What information will be legally acceptable? What resources are available for the task?

North American biologists face a broad range of water pollution problems. Their nature determines why, where, and how biological skills are put to use in the North American water pollution control field. There is broad geographic diversity in bodies of water, also. They range from upland, shallow and rapid streams to lowland, deep, slow and oftentimes impounded rivers; from short streams to rivers 2470 miles long; from shallow and warm to deep and cold lakes, from stabilization ponds a few tenths of an acre in area to Lake Superior with 31,820 square miles; from estuaries in three coastal areas to the frontage of two oceans, the Gulf of Mexico and contiguous waters.

In the United States, pollutants vary widely. Raw or treated sewage is discharged from 11,420 cities with a total of 123 million people (Anon., 1964 a). Industrial wastes of many kinds stem from the attainment of an annual gross national product of about $ 700 billion. Surface runoff flows from 3,615,222 square miles of land in the United States, 3,560,238 in Canada, and 761,830 in Mexico. These flows carry natural organic materials, pesticides, and plant nutrients. Radioactive substances originate in the production, use, and disposal of nuclear mate-

rials. Heat is added through cooling operations, discharge of hot process waters, and from the sun.

The principal water uses affect the specific interest of the biologist and determine what he must study. Frequently, his findings justify the imposition of a water quality management program. He also defines the practices needed to protect or enhance sport and commercial fisheries, water supplies, recreation, and waterfront land values. His mode of approach is also governed by the laws pertaining to water resources. The significance of some of these challenges will be discussed in detail to reflect the reasons for the practices and views of North American professional biologists.

The writers are most familiar with the views of personnel and programs in their own country, but those of workers in Canada and Mexico have been solicited for the following remarks. This fact, and the magnitude of the United States water pollution control program, explains the authors' subsequent emphasis on such matters in the United States.

Kinds of pollutants

In the United States, a national policy on the necessity of adequate treatment of municipal sewage has existed for some time. This policy is expressed in Federal legislation[1] providing grants of funds by the United States Government to cities to help finance needed waste treatment works. The policy is also expressed in the performance of the Congress, which has appropriated from 45 to 100 millions of dollars annually for this purpose over the past eight years. Municipal treatment works numbering 6,079 and costing more than three billion dollars have been established under this program. Only 52 United States cities of 25,000 population or more do not now have facilities[2].

The saprobic system originated as a result of the study of water problems caused by sewage discharged to slow and evenly flowing rivers. This is still apparently the area of its most facile application. Considering the current municipal waste treatment plant construction program in the United States, it is not surprising that the saprobic system and its various modifications are little used to determine the treatment facility needs of a given city. In the limited instances when it is used, the typical objective is not to determine the existence and magnitude of pollution, but to obtain colorful biological data for an anti-pollution campaign. When used in simplified, expressible form in community meetings, television, radio, schools, and the like, such data help to shape a favorable public attitude toward the remedial program (Ingram and Bartsch, 1960). It is mainly when the anti-pollution campaign enters legal or quasi-legal stages that detailed biological study may become necessary.

Principles of the saprobic system obviously apply to other wastes that share

[1] Public Law 660 — 84th Congress, Section 6.
[2] March 1965.

characteristics with sewage, such as appreciable BOD and settleable solids; for example, wastes from pulp and paper, food processing, meat packing, and tanning. Their impacts on the biota are generally known, so that the saprobic system is useful to detect pollution or to support physical and chemical observations. In the United States, however, water pollution problems caused by these industries either: (1) are not pressing, (2) require remedial measures that are obvious, or (3) require specific procedures beyond the scope of the saprobic system.

Toxic industrial pollutants from a wide variety of industries are a greater challenge. In addition, there are particulate wastes, such as mineral refining fines and slimes, lost fiber and bark from pulp and paper manufacture. These wastes, whether toxic, particulate, or both, decrease or eliminate productivity at a low trophic level or may destroy fish and other aquatic life directly.

An accurate and complete assessment of fish destruction and fishery impairment resulting from pollutional influences cannot be obtained. Nevertheless, the United States Public Health Service does operate a nationwide reporting system that approximates the magnitude of this loss. The latest report (ANON., 1964 b) shows that 18,387,000 fish were reported killed by water pollution in 40 of the 50 States during 1964. There were 485 fish kill episodes. The devastation and resource loss from such fish kills are obvious. While observations on benthic organism densities and distribution following such episodes may help identify the source of the toxicant and forecast the time required for benthic recovery, the saprobic system itself is not helpful.

As the discrete and classical sources of water pollution come under acceptable control, the diffuse drainage from the land takes on increasing significance at many points in the United States. Some of the problems include effects of timber harvesting on watersheds that serve municipal or industrial water supply needs, but more pressing are problems related to drainage from agricultural lands. Voluminous drainage and return flows, especially from irrigated land, increase the silt loads and give unfavorable total dissolved residue balances to receiving streams. Frequently, an undesirably high sodium content is acquired as well. Of more recent concern is the runoff of pesticides applied to the land to increase crop yields. Recent evidence shows that DDT, for example, is now found practically everywhere on this planet. In some regions where return flows ultimately reach quiescent waters, the nutrients they contain contribute to accelerated eutrophication. Impairment of lakes through production of algal blooms is a growing problem in North America. Lake Erie, with its 9940 square miles, is under intense study to curb this affliction.

Again, while the whole range of biological responses to these conditions is profoundly interesting and must be examined, the saprobic system does not delineate the problem nor propose a solution.

Thermal pollution is coming under increasing scrutiny in North America. Undesirable temperature changes come about from three principal sources. First is the

direct addition of heat through industrial process cooling, such as at power installations and manufacturing plants. Resulting problems are under study at a number of places (Brett, 1960; Trembley, 1960, 1961; Coutant, 1962; Anon., 1962; and Warinner and Brehmer, 1964). A second heat source comprises the nuclear reactors, such as those on the Columbia and Savannah Rivers in the United States and the Chalk River in Canada. A third is the heating, or cooling, of water, either by influences of the terrain — such as desert, canyons with heat-reflecting walls, vegetative cover — or as a result of storage in reservoirs. A concerted research effort is now being made to understand the interacting factors that contribute to such temperature changes.

In western North America, excessive warming of waters is undesirable because it violates the environmental requirements of salmonid fishes, including trout, steelheads, and five species of Pacific salmon. Elsewhere, the problem involves heat that upsets the seasonal velocity or course of events in the life histories of warm- or cold-water fishes and their food organisms, or alters stream self-purification capacities and rates.

While the problems of heat pollution and the resources affected are strongly biological, use of the saprobic system is not an effective approach to them.

Bodies of water

As stated earlier, the water pollution problems in the medium and large, slow-flowing rivers on which major cities are located either are remedied through adequate waste treatment or the technical remedial needs are known. This is true also for most industries producing putrescible organic wastes. In the swift streams, where the saprobic system might be used, the biologist is faced with the mechanical problem of effective and adequate sampling (Usinger and Needham, 1956), the challenge of relating biological affairs in riffles to those in pools, detecting specific organism responses to stream velocity, and the complex task of interpretation. Fortunately, in such waters, interest usually is not directed to the saprobic state of the stream but goes a step beyond to the direct question of how well the environment qualifies for fish production, recreation, water supply, or some other use.

Although the North American continent has many lakes — the State of Michigan has 11,037, Minnesota, 15,292, and Wisconsin, 4136 — few of their pollution problems relate to the deoxygenating effects of putrescible wastes. Induced eutrophication, resulting in unwanted blooms of blue- green algae, interferes with recreation and other uses of water. Such problems are common and increasing in rich agricultural areas and in lakes receiving municipal drainage. Current efforts to cope with this problem are being greatly intensified.

No major river system of the United States is without impoundments. The effects of the Tennessee Valley Authority water resource developments on water quality are well known and have been studied intensively (Churchill, 1957,

1958; DUNCAN, HARLEMAN and ELDER, 1962). Water resource developments in the Missouri River Basin are practically complete. Harnessing the Columbia River system for power production, flood control, irrigation, and other purposes is well along, with a system of 89 major existing impoundments and 24 under construction, or planned.

While there is interest in the effects and fate of pollutants in selected reservoirs, such interest does not usually include the saprobic status, but rather the questions: How do pollutants respond to the density gradient regimen? Do the wastes contribute significantly to algal production? What are the relationships of photosynthesis and stratification to the dissolved oxyoen resources?

Estuaries and near-shore waters have been the last to receive attention in North America. Although some of the major cities are located adjacent to such waters, increasing waste discharges have aroused public indignation only in recent years as water use pressures and recreational needs have grown. One stimulus for action was a recent shellfish-borne outbreak of infectious hepatitis, which resulted in closure of shellfisheries at Atlantic and Gulf Coast points.

Industries also are locating increasingly at coastal sites. These developments, coupled with more intense competition for use of coastal water resources, have stimulated vigorous investigative programs in several estuarine waters. Notable among them are current or recent large-scale studies on Raritan Bay, Chesapeake Bay, the Savannah, Waccasassa, and Fenholloway river estuaries in eastern United States, Charleston Harbor, kelp investigations in southern California, San Francisco Bay, and Puget Sound. Six additional coastal and estuarine areas have been studied vigorously in Canada. These studies embrace a wide range of water use considerations. In every instance the existing biotic conditions are scrutinized, but usually for specific biological purposes apart from application of the saprobic system. In fact, too little work has been done in North America to date to determine if, how, and to what extent the system is applicable to salt water environments (FELICE, 1954 a; MOHR, 1960; REISH, 1960).

Practices of North American biologists

In North America, biological efforts to detect and measure pollution proceed at two intermingling levels. One category comprises the total research on the fundamental ecological relationships occurring in environments altered by pollution as well as on organism responses to specific pollutants. Such research provides a better understanding of how biology may be used with increased confidence to solve practical problems. During fiscal year 1964, the United States national water pollution control agency supported 94 biological research activities related to assessment of water pollution at an annual cost af about $ 2 million (Table 1).

Additional research is supported by state, interstate and local agencies, by industrial organizations and by individual companies. The precise magnitude of this additional effort is not known.

The other category of related scientific effort includes the biological investigations by governmental agencies, industries, and their consultants to solve existing or impending water pollution problems. Occasionally, such work yields new basic information, but more commonly its ancillary contributions include newly evolved schemes for data interpretation and portrayal.

Table 1. United States Federally Supported Research on Biology of Water Pollution — F. Y. 1964.

Number		Cost
48	Research Grants	$ 953,694
31	Fellowships	199,363
10	Training Grants	343,193
5	In-House Projects	364,900
94		$ 1,861,150

Questionnaires from 159 North American biologists working in these fields provided interesting and representative information concerning use of the saprobic system. Only 36 find the saprobic system useful, and only 14 use it in essentially original form. Of those using the system, only 3 biologists depend on it alone to detect and measure pollution, with most biologists augmenting these observations with chemical sampling and analyses, bacteriological determinations, waste source surveys and inventories, or other procedures. Foreign or American published modifications of the saprobic system are used by 18 biologists, while 20 use their own unpublished adjustments in procedure.

Additional analysis of questionnaires showed 78 use routine short-term bioassays, 53 use *in situ* bioassays, and 49 use other bioassay alternates to solve their biological water pollution problems. Measurements of basic production, whether using carbon-14, light and dark bottle, pigment analysis, or other techniques, are prominent in water pollution biology. Fifty-two biologists use these approaches.

Biologists' views were also solicited on the use of several published North American ecological approaches. From the response, many biologists prefer an approach they have designed themselves, no single approach is acceptable to many biologists, and there is little agreement as to a logical course to pursue. It appears that there are about as many procedures as the number of biologists working in this field. Many of the procedures are continually being modified so that this obviously is not an appropriate time to consider a single scheme for a standard method. In fact, one can well question whether a standard method is possible or even desirable.

Many deficiencies in the saprobic system have been identified by these respondents as reasons for avoiding its use. In summary, the reasons are mostly related to: (1) necessity to identify organisms as to species with only poor taxonomic tools available, (2) paucity of basic knowledge on the ecological characteristics and requirements of individual species and communities, (3) failure

to properly quantitate species relationships, (4) complications caused by the physical complexities of the watercourse, (5) failure to accommodate the uniqueness of each stream, each pollutant, each problem, (6) questionable applicability of the saprobic system to estuaries and coastal waters, and (7) restriction of use to pollution caused by municipal sewage or similar acting organic wastes.

Taxonomic Problems

It is basic to the use of indicator organisms that they be identified as to species, because, whatever their indicator capacities may be, it is presumed to be at the species level and not at higher taxonomic echelons. In North America there is great diversity of species among the benthic invertebrates so that the sheer numbers to be dealt with are tremendous. Moreover, in the vast expanses from the Atlantic to the Pacific oceans, with various migration barriers in between, there is great geographic and genetic variation in floras and faunas. As a result, a biologist familiar with the biota in one region may find a new array of unfamiliar organisms in another. Taxonomic consultants are not plentiful; in fact, taxonomy has become an unattractive specialism in this age of rockets and outer space. These taxonomic difficulties, coupled with the time requirement for physical separation of samples as to species, are among the greatest drawbacks of the saprobic system. One biologist referred to this problem simply as, "Too much time, too many people, too much money".

Ecological Characteristics

One criticism of the saprobic system is that it implies more knowledge than exists of the ecological characteristics, environmental requirements, limits of tolerance, and physiological responses to pollution. Little is known of the environmental requirements of benthic organisms in either polluted or unpolluted waters. Difficulties have been encountered because biotic responses to physical characteristics of the watercourse — to size, depth, velocity, upland versus lowland, bottom characteristics such as silt, sand, rock, wood bark, or fiber, a watershed of limestone versus granitic rock — override, obscure, or confuse responses to pollution. Certainly, the response of one organism to another, and the interrelationships of carnivores, omnivores, and herbivores, help to determine the size and nature of the benthic population. Lack of knowledge on life histories of many organisms with their seasonal developments further complicates the problem.

Uniqueness of the Aquatic System

Many North American biologists expressed the conviction that each aquatic system is unique, that benthic communities fail to comply reliably with any system, and that "pollution indicators" can be found in unpolluted environments, also. Richardson (1928), for example, noted that "... the number of small bottom-

dwelling species of the fresh waters of our distribution area that can be safely regarded as having even a fairly dependable individual index value in the present connection is surprisingly small." Similarly, INGRAM (1957), in discussing the indicator values of freshwater mollusks, stated that "... not enough is known yet about molluscan ecology to name any species a pollution indicator." Other workers (GAUFIN, 1960) have experienced the same deficiencies. Nevertheless, wefts of *Sphaerotilus*, abundance of Tubificid worms, or members of the genera, *Tubifera* and *Asellus*, signal a harder look at the pollution status. There is also a feeling of danger in relying too heavily on the "system" and consequently missing the true picture. As one person stated it, "Schemes should not stop biologists from working and thinking."

Marine Waters

Nowhere have biological studies of pollution in estuaries and coastal waters traced as long a history as in fresh water. Studies in San Francisco Bay (FELICE, 1954 b) showed three benthic zones surrounding a waste outfall: an outer zone unaffected by waste discharges, an intermediate zone inhabited by tolerant organisms, especially polychaetes, and an inner, practically uninhabited zone. Similar findings were made by REISH (1955, 1957) who also noted that *Capitella capitata* (FABRICIUS) was the animal most characteristic of the organically polluted area. In Biscayne Bay, Florida, MCNULTY (1964) found benthic populations depressed near sewage outfalls, but increased outside this zone.

Various North American biologists have expressed doubt as to the applicability of the saprobic system to coastal and estuarine environments. In relation to estuaries, at least, there is question as to how much of the observed biological response is caused by: (1) change in flow velocity, (2) shift from fresh to saline water, or (3) change from unpolluted to heavily polluted conditions. The question of applicability of the saprobic system in such waters is not a popular one and has not received the attention it deserves. A recent Conference on Estuaries[3] hardly touched the subject in its 76 papers. Similarly, althoug the Second International Conference on Water Pollution Research[4] devoted one of its three sections to marine disposal, the saprobic system was not included.

It is not enough to merely report that North American biologists do not routinely use the saprobic system and to point out the impelling reasons for this. One must also outline the developing evolution in the use of biology to detect and measure pollution. It is generally attempted to design the approach to the specific needs of the problem — requiring consideration as to the type of body of water and the specific environment concerned — as to depth, type of bottom, and related

[3] Conference on Estuaries, Jekyll Island, Georgia, March 31—April 4, 1964.
[4] Second International Conference on Water Pollution Research, Tokyo, Japan, August 24—28, 1964.

characteristics. Also impelling are the questions: What are the water uses of concern? What uses are allegedly impaired? What pollutants are involved?

Following are two examples showing how biology, teamed with other professional skills, seeks to solve problems of national importance.

Example 1.

Since spring of 1962 a joint Federal-State field study has been under way at four locations on Puget Sound, Washington, where seven pulp and paper mills discharge wastes. The study has been made as comprehensive as the available resources permit to ascertain the effects of these wastes on the area's waters and marine resources — salmon, oysters, crabs, and clams. The program consists of four major elements: in-plant surveys, oceanographic, biological, and economic studies (BARTSCH, et al. 1964, BARTSCH 1964).

The biological studies are designed to detect and measure pollution-induced changes in the environment and their impacts on marine organisms. Nine related schemes were used as follows:

Elements of Investigation	Frequency	Utility of Technique
I. Vertical and horizontal tow collections of plankton	Monthly	Pending[5]
II. Submerged microslides for attached organisms	10 days	Pending[5]
III. Productivity and nutrient supply	Monthly	Pending
IV. *In situ* bioassay for mortality, growth, and condition index of adult oyster, *Crassostrea gigas* (THUNBERG)	Monthly	Excellent
V. Bioassay of oyster larva, *Crassostrea gigas* (THUNBERG)	Monthly	Excellent
VI. *In situ* live box bioassay, juvenile salmonids, *Oncorhynchus keta* (WALBAUM), *O. tshawytscha* (WALBAUM)	Summer	Good
VII. Distribution-migration juvenile salmonids	Spring and Fall	Good
VIII. Bottom fisheries, trawling	Monthly	Fair
IX. Bottom fisheries, laboratory bioassay with eggs and larvae of English sole, *Parophrys vetula* (GIRARD)	January to April	Excellent

The results of these studies give a fairly complete picture of the current state of habitat suitability and go far toward assessing the impacts of pulp and paper wastes on the living marine resources of the area. They also develop, improve, or test biological practices not previously applied in this way.

Example 2.

The second example is an investigation by the United States water pollution control agency of large-scale fish kills in the lower Mississippi River area. These kills have destroyed an estimated 9.3 million fish since 1960. Many were channel catfish

[5] Requires advanced computer treatment; data not yet processed.

(*Ictalurus punctatus Rafinesque*), a valuable commercial species. Initial observations showed that the more commonly examined elements of the environment, such as dissolved oxygen, pH, temperature, and river discharge, were not unusual. It was also noted that the dead or dying fish consistently showed the same symptoms — hemorrhage around the mouth and sometimes the fins, distention of the abdominal area because of gas in the air bladder and digestive tract, and lethargic, often inverted swimming at the surface. Large quantities of air or gas were emitted from the mouths of some fish. Pesticides were suspected, and subsequently proved by this investigation, to be the cause of the mortalities.

This investigation is an excellent example of joining the skills, knowledge, and experience of several professional disciplines — the microbiologist, chemist, toxicologist, biologist, engineer, hydrologist, and others — to solve a most difficult and complicated problem (ANON. 1964 c). Several phases of the work are still in progress. The following outline shows how biological and related talents have been used on this problem.

Elements of Investigation

I. Examination of usual environmental factors.

II. Elimination of parasites, bacterial or viral diseases and botulism as causes of mortalities.

III. Considerations of toxic substances:
Examination and prognostication of symptoms of dying fish.
Autopsy, including:
Haematocrits and white cell counts.
Kidney tissue study.
Brain tissue assay for organic phosphorus insecticide.
Tissue analysis for 19 potentially toxic metals.
Gas chromatographic analysis of tissues, including blood, for chlorinated hydrocarbon insecticides.

IV. Explorations for toxic substances:
Bioassay with Mississippi River water.
Bioassay with extracts from river bottom mud.
Bioassay with tissue extracts from fish dying in river water and bottom mud extracts.
Bioassay with endrin to compare symptoms and tissue extract analyses with those of dying fish in all bioassays.

V. Intensive chemical analysis for pesticides in the natural environment, experimental environment, river fish, and experimental animals.

VI. Surveillance of surface waters for geographic range and intensity of pesticide contamination.

VII. Correlation and interrelation of findings.

The investigation was designed to consider and eliminate potential fish kill possibilities that were not involved and come to a point focus on the real cause. It was found that the massive kills were not caused by disease, heavy metals, organic phosphorus compounds, lack of dissolved oxygen or unsuitable pH. Blood of dying river fish was found to have concentrations of endrin equal to or greater than laboratory fish killed with this pesticide, while living fish had lesser concentrations. Symptoms of both groups of dying fish were identical. It was concluded from all data obtained that these fish kills were caused by endrin poisoning.

Conclusion

The two examples given emphasize that North American biologists engaged in water pollution control activities increasingly focus their skills and energy on extraordinary problems. In doing so, they utilize the saprobic system, parts of it or derivations from it, as long as the system contributes to problem solution. At present, however, most North American pollution problems are not solved by use of the saprobic system.

Acknowledgment

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Discussion

Caspers: What is your opinion on the method of Dr. Patrick's studies and their value for the evaluation of the water quality?

Bartsch: The diatometer procedure, while mathematically sound, has not become popular mostly because there are too few biologists in the United States who know diatom taxonomy sufficiently for this purpose.

Sládeček: In American literature I found several terms, e. g. "healthy, semi-healthy, polluted, very polluted" at R. Patrick (1951) or "degradation, active decomposition, recovery, clean water" at Bartsch (1948). I think that these terms can be synonymized with the terms of Kolkwitz and Marsson relatively with ease.

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